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13. ABSTRACT *(Maximum 200 words)*
Developments in adaptive materials (or smart structures) have led to their use for actuators in aeroservoelastic applications. Tests demonstrating feasibility of adaptive materials based actuation have been conducted on small geometrically scaled models, and aeroelastic scaling has been disregarded. The primary objectives of our research activity were: (1) development of innovative aeroelastic scaling laws for aeroservoelastic and nonlinear aeroelastic problems, which allow one to extrapolate results, obtained from model tests to the full-scale configuration, and (2) application of the scaling laws to configurations illustrating difference between geometric and aeroelastic scaling. The primary accomplishments were: (1) development of a novel two pronged approach for generating innovative aeroelastic scaling laws for nonlinear aeroelastic and aeroservoelastic problems, and (2) developed scaling laws for flutter suppression in subsonic and transonic flow. In addition to conventional scaling parameters these requirements also address the sealing of control hinge moments and power required for flutter suppression. The research described has made an important contribution to the state-of-the-art.

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BACKGROUND AND OBJECTIVES

Recent advances in the area of adaptive materials (or smart structures), have led to the use of such materials as actuators for aeroservoelastic applications. The attractiveness of such materials is their potential for introducing continuous structural deformation of the lifting surface that can be exploited to manipulate the unsteady aerodynamic loads and prevent undesirable aeroelastic effects such as flutter. While the potential of piezoelectric actuators for aeroservoelastic applications is substantial, major limitations on their stroke and force producing capabilities exist. Therefore, tests demonstrating feasibility of adaptive materials based actuation have been conducted on small geometrically scaled models in incompressible flow. In these tests aeroelastic scaling has been disregarded and the question of how one would scale such actuators for different sized models, or actual full scale configurations has been has not been carefully addressed. Furthermore it should be noted that research on aeroelastic scaling has focused primarily on flutter or aeroelastic stability and practically no research on nonlinear problems or aeroservoelastic applications exists.

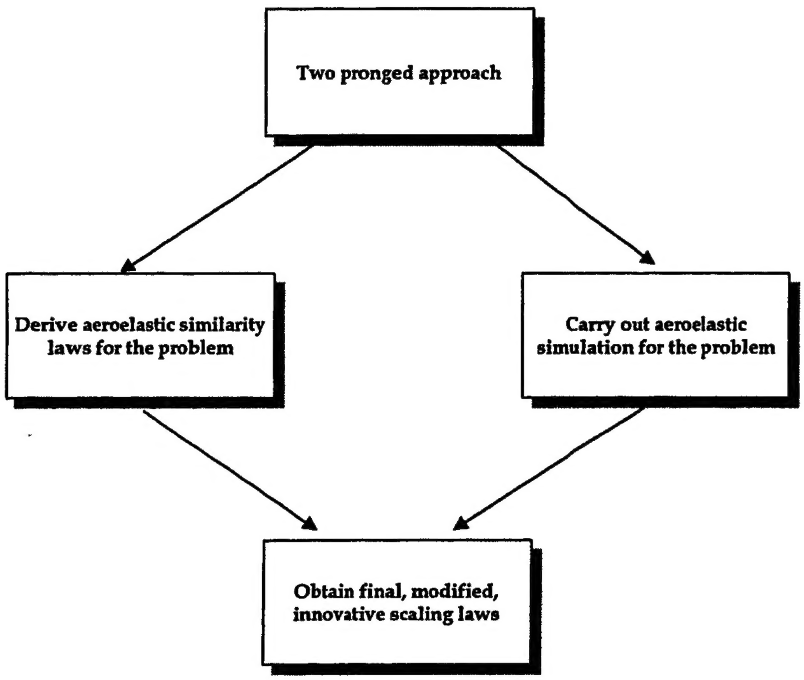
The primary objectives of our research activity were:

- Development of innovative aeroelastic scaling laws for aeroservoelastic and nonlinear aeroelastic problems, which allow one to extrapolate results, obtained from model tests to the full-scale configuration.
- Principal emphasis was on aeroservoelastic applications where scaling of hinge moments, control forces and control power required for flutter suppression (using both adaptive materials based actuation, as well as conventional control surfaces) is important.
- Application of the scaling laws to configurations illustrating difference between geometric and aeroelastic scaling. Use of scaling relations to illustrate equivalence

between conventional trailing edge flap actuation and bend/twist coupling based piezoelectric actuation.

APPROACH

A novel two pronged approach for establishing scaling laws has been developed. In this approach, illustrated in the figure provided bellow, basic aeroelastic scaling



Schematic diagram depicting two pronged approach for generating innovative scaling laws

parameters are established using the conventional approach consisting of a typical cross sectional aeroelastic analysis combined with dimensional analysis, as illustrated in the left hand side of the figure.

In parallel refined solutions, or simulation codes, are developed for each aeroelastic or aeroservoelastic problem for which innovative scaling laws are desired. Results obtained from such simulations play the role of "similarity solutions", in the context of similarity theory. These results provide new information on the scaling requirements of actuation forces and moments needed for flutter suppression as well as power requirements for flutter suppression. The right hand branch of the figure above illustrates the scaling information obtained from the computer simulations. Combination of the classical similarity parameters obtained from the left-hand branch, with those obtained from the

right-hand branch yield the final comprehensive aeroealstic scaling requirements for the problem.

RESULTS

The approach described above has been applied to a number of aeroservorelastic problems and has resulted in a total of six publication listed in the final section of this concise report, which also serves as a list of References.

The **first problem** considered was the adaptive control of aeroelastic instabilities in transonic flow and its scaling. A two dimensional typical cross-section in inviscid transonic flow was considered. The unsteady aerodynamic loads were obtained from the exact solution of the Euler equations. The digital adaptive control law, based on an ARMA model, was implemented using a trailing edge flap. Active flutter suppression in, presence in presence of nonlinear aeroelastic phenomena, was demonstrated, at velocities 20% above the flutter speed. Aeroelastic scaling requirements governing actuator hinge moment and control power were established. This research was documented in Refs. 1 and 2.

The **second problem** considered was the flutter suppression of a typical cross-section in subsonic compressible flow, using time domain aerodynamics and a trailing edge control surface. The control law was obtained from LQR approach with full state feedback. With practical limits implemented on the magnitude and rate of the control deflection, combined with appropriate disturbances, flutter suppression at 10% above the flutter speed was obtained. Further incr3eases in flutter speed caused control surface saturation. Saturation ot he control surfaces, causes the system to become nonlinear, and control techniques such as LQR fail, preventing further increases in velocity. This saturation problem represents a significant obstacle to flutter suppression since current techniques in adaptive and nonlinear control theory can not deal effectively with this situation. Basic aeroelastic scaling laws for this problem were also obtained, together with the requirements for scaling hinge moment and power needed for flutter suppression. It was also shown that geometric scaling leads to the violation of aeroelastic scaling requirements. This research was documented in Refs. 3-6.

The **third problem considered** was the development of equivalence relation between flutter suppression on a two dimensional section using and actively controlled trailing edge flap and piezoelectric actuation utilizing bend twist coupling in a three dimensional wing. It was shown that piezoelectric actuation requires almost an order of magnitude more power than the actively controlled wing.

ACCOMPLISHMENTS

The primary accomplishments of this research are listed below.

- Developed a novel two pronged approach for generating innovative aeroelastic scaling laws for nonlinear aeroelastic and aeroservoelastic problems. This approach has re-cast the subject of aeroelastic scaling in the framework of modern aeroelasticity. This approach is general and can be applied to any aeroelastic problem. The classical approach, that has remained unchanged during the last 35 years, has been superceded by the new approach, and thus the current research has made an important contribution to modern aeroelasticity.

- Scaling laws for flutter suppression in transonic flow, in presence of moving shock waves, have been developed. In addition to conventional scaling parameters these requirements also address the scaling of control hinge moments and power required for flutter suppression.

- A similar treatment of the flutter suppression in subsonic compressible flow has identified saturation, and its treatment as a major hurdle in flutter suppression. Previous researchers in aeroservoelasticity overlooked the precise severity of this problem. It was also shown that geometric scaling results in serious violations of the aeroservoelastic scaling requirements.

- Power requirements of piezoelectric actuation, based on bend-twist coupling, for flutter suppression in subsonic flow are considerably higher than those needed for flutter suppression using an actively controlled trailing edge flap.

- In the course of this research one M.S. student (D. Guillot) and one Ph. D. student have completed their degrees.

LIST OF PUBLICATIONS PRODUCED UNDER THE GRANT (References)

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